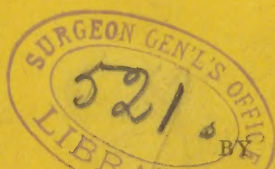


Dulles (C. W.)

THE MECHANISM

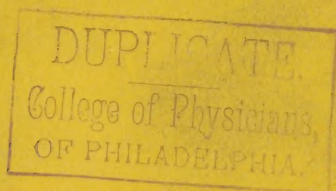
OF

INDIRECT FRACTURES OF THE SKULL.



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FELLOW OF THE COLLEGE OF PHYSICIANS AND OF THE ACADEMY OF SURGERY OF PHILADELPHIA; SURGEON
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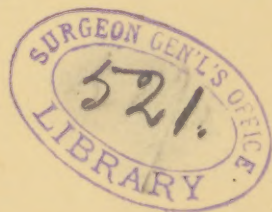


SOLD.

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MECHANISM
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INDIRECT FRACTURES OF THE SKULL.

✓
BY
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THE MECHANISM

OF

INDIRECT FRACTURES OF THE SKULL.

HISTORICAL STUDY.

THE earliest authentic mention of a fracture of the cranium occurring at another point than that upon which the violence which caused it was applied, is to be found in the writings of Hippocrates, who lived about 500 years before the Christian era. To call him a surgeon may seem startling to some who have thought of him only as the author of the oldest medical work now extant; but that he was a surgeon of great sense and acuteness his writings abundantly testify. Nor should it give offence to any that he should be claimed for the fellowship of surgeons, since, as Justamond has pointed out, in one of his admirable essays,¹ the practice of surgery must have antedated that of physic; for, as he remarks: "In the primary ages of mankind, when the most perfect of all created beings had yet scarce degenerated from that state of perfection in which he was first produced from the hands of the Creator, disease

¹ Outlines of the History of Surgery. Surgical Tracts of the late J. O. Justamond, F.R.S. etc. London, 1789.

was yet unknown upon the earth. Man had then no wants but such as the neighboring stream or the labor of his own hands would supply, no cares but those of a domestic nature, amply compensated by the satisfaction which attends them. His mind was not yet weakened by intemperance, nor his body impaired by debauchery; exercise was his only physic, and unbroken, undisturbed rest his only restorer. But, even in those happy and tranquil times, man was not exempt from the consequences of accidental violence. His body was not less exposed to common casualties and to a variety of strokes that might bruise or wound the flesh, or dislocate or fracture his bones. He might be torn by the fangs of some wild beast, or affected by the bite of some venomous insect. Such were the first and most natural evils to which man, in the place assigned him in the order of created beings, must have been obnoxious, and therefore his thoughts would necessarily be engaged in finding out some means of relief for these accidents. Thus, from the nature of the subject, as well as from the testimony of Celsus and many other remote authors, it appears that surgery was incontestably the most ancient branch of medicine, the parent of all the rest."

Hippocrates, then, the father of surgery, let us say, gives the earliest definition of the fractures we are about to study: § 8. Ὁστέον τιτρώσκεται ἄλλη τῆς κεφαλῆς, ἢ ἢ το ἔλκος ἔχει ὠνθρωπος, καὶ τὸ ὁστέον ἐψιλώθη τῆς σαρκός, etc.¹ (The bone is broken in another part of the head than that in which the man received the injury, and the bone was stripped of the flesh.)

This definition remained unimproved until more than

¹ Hippocrates. Œuvres Complètes d'Hippocrate, par E. Littré. 10 vols. 8vo. Paris, 1841. Vol. iii. p. 211.

two thousand years later, when, in 1873, Félizet suggested the division of fractures of the cranium into "immediate and mediate;"¹ if, indeed, this suggestion be an improvement.

Hippocrates despaired of the cure of fractures remote from the seat of the wound, and seems to have had no more definite idea about them than that they might occur.

The next author, to whose writings access may still be had, who refers to this subject, is Celsus, who lived about the beginning of the Christian era. Celsus says: "Solet etiam evenire, ut altera parte fuerit ictus, et os alterâ fiderit." (It sometimes happens, also, that the blow has fallen upon one point, and the bone is cleft in another.) He furthermore recommends cutting down upon any point where there is softening and swelling, in case no fissure is found at the point struck, and bad symptoms arise.² Here was a decided advance upon the teaching of Hippocrates, another being the observation of Celsus that the vessels of the brain might be ruptured without fracture of the cranium, anticipating a much later explanation of the term "*contrecoup*."

Soranus³ (97-117 A.D.) says: "Resonantia secundum aliquos est facta in calvariæ partibus fractura oppositis iis quæ percussæ fuerunt, sine vulnere superpositum."

Oribasius (about 350 A.D.) says: "Ceterum quæ ab ipsis dicitur resonantia, rima quædam est, quæ non quo fuit ictus, sed adverso loco sit, simili ratione ac in vasis

¹ Félizet, G. Recherches anatomiques et expérimentales sur les fractures du crâne. Paris, 1873. P. 160.

² Celsus Aur. Corn. Celsi de medicina libri octo, cum notis integris . . . cura et studio Th. J. ab Almeloveen, etc. 8vo. pp. 749, Ludg. Batav., 1746. Lib. viii. De calvaria fracta.

³ Soranus. De fracturarum signis, etc. Florentiæ, 1754. Pp. 46 and 47.

fictilibus, quæ altera parte percussa, in alteram rimam accipiunt.”

It is said in many of the more recent works on counterstroke that Paul of Ægina (about 500 A. D.) denied the occurrence of the fractures at a distant point. For this denial, however, he offered an explanation which was considered wise when it was suggested as original about 1200 years later, namely, that the fractures attributed to counterstroke are chargeable to other blows, received after the first: by a fall, for example.¹

The teachings of these great men were but little modified in many centuries.

In 1535 Berengarius discussed most intelligently the possibility of a fracture in an opposite part of the skull without lesion of the part receiving the blow. After going over the ground pretty thoroughly and asserting the ease and frequency with which multiple fractures, and fractures caused at the opposite side by a fall after the blow has been received, may be, and have been, misinterpreted, he concludes that he cannot deny that a true, independent, opposite fracture may occur.²

The idea of counterstroke was, so far as my investigations go, first plainly and unequivocally defended by Paw, who, in 1616, says that a blow may fracture not only another part of the skull, but even an opposite one; thus the forehead being struck, and remaining intact, the occiput may be fissured, or when one tem-

¹ Paulus Ægineta. The Seven Books of Paulus Ægineta. Translated by Francis Adams. Sydenham Soc. London, 1846, 3 vols. Book vi., Sect. xc.

² Tractatus perutilis et completus de Fractura Cranii, ab eximio artium et medicinæ Doctore D. Magistro Jacobo Berengario Carpensis, etc. 8vo. folii iiiii. cx. Venetiis, MDXXXV., capitulum ii. ff. x-xiii.

poral or parietal bone has received the blow, the opposite one may give way.¹ He also notes a case in which he found, at the autopsy, that the outer plate of the bone which was struck remained unbroken, while a fragment was detached from the inner one and driven into the brain.²

In 1649, Guillemeau expressed doubt as to the occurrence of fractures by counterstroke, which, he says, many writers speak of. "Mais," he says, "telle fracture n'est iamais venuë à ma cognoissance & ne me puis persuader qu'elle puisse aduenir, si ce n'est quand les sutures sont serrées & vnies ensemble, ou perduës depuis l'os frappé, iusques à celuy qui se trouue à l'opposite fracturé."³

In the same century Boerhaave recognized the fact that the brain may be lacerated or compressed, though the skull remains entire, and Van Swieten, in commenting on this statement, explains the phenomenon as due to the momentum communicated to the brain, which dashes it against the resisting interior of the opposite side of the skull.⁴ Van Swieten also called attention to the possible injury of the diploë alone, without fracture of either table of the skull.⁵

Still in the seventeenth century, Stalpart van der Wiel speaks most unequivocally of lesions of the cranial contents at a point opposite to that which has

¹ Petri Paaw Amstelodamensis succenturiatus anatomicus continens commentaria in Hippocratem, de capitis vulneribus, etc. Lugduni Batavorum, Ann. MDCXVI.

² Ibid., p. 108.

³ Jacques Guillemeau. Les Œuvres de Chirurgie. Folio. Rouen, 1649. De la contrafente aux os de la teste, p. 656.

⁴ Van Swieten. Commentaries on Boerhaave's Aphorisms. Translation. 18 vols. 8vo. Edinburgh, 1776. Vol. ii. p. 399.

⁵ Ibid., p. 339.

received a blow, giving this as a justification for trepanning.¹

In 1708, Wagner published a thesis on contrecoup in which he quotes Fabricius de Aquapendente (1537-1619) as explaining it by the efforts of the air, which he supposed the skull to contain, to escape from the side opposite to that on which the blow was received. Marcus Marci, he says, attributed it to the spheroidal shape of the skull and the special violence of the blow.²

In 1764, Aurran published a paper to show that the location of a fracture by contrecoup could be certainly determined. In this paper he calls attention to the fact that the sutures of the skull do not set a limit to a fracture. He claims that the temporal regions are most liable to fracture, partly because they are comparatively thin, and partly because of their architectural peculiarities, since they embrace the parietals and are driven asunder by blows which fall upon the vault of the cranium.³

Soon after this, occurred a veritable epoch in the history of our subject. The Royal Academy of Surgery of Paris, which had been founded in 1631, proposed in 1760, and again in 1765, as the subject for a prize, the following proposition: "To establish the theory of counterstroke in lesions of the head; and the practical conclusions which may be drawn from it." On the first of these occasions the prize was not awarded; on the

¹ Stalpart van der Wiel. *Observ. rariorum* . . . *Centuria prior*. 16mo. Lugduni Batavorum, 1687. *Observ. VII.* and comments on it.

² Wagner. *Sur les Contrecoups*. Haller's *Collection de Thèses*. 5 vols., 12mo. Paris, 1757. Tome i. pp. 11-28.

³ Aurran. *Observations sur les contre-coups, qui tendent à prouver qu'on peut découvrir sûrement l'endroit fracturé, selon le lieu qui a reçu le choc*. *Journ. de Méd., Chir., et Pharmacie*, Paris, 1764, tome xxi. pp. 252-260.

second, it was awarded to Grima,¹ who sent in for the second time the same essay which he had sent in for the former competition, and which had been thought the best at that time.² The same question was proposed for the prize of 1768, when prizes were awarded to Saucerotte³ and Sabouraut,⁴ for which Chopart⁵ also presented an essay, which was accepted and published by the Academy. Chopart not only recognized the elasticity of the skull, but exaggerated it, and, as a diagram in his essay shows, believed that a blow produced alternating and reciprocal shortening and lengthening of the axes, in a manner which some authors describe as undulatory.

Nor would the history of this epoch be complete without mention of a valuable memoir upon counterstroke in other parts than the head,⁶ written by David, though published under the name of his pupil, Bazille—to which a double prize was awarded in 1771.

All of these writers considered the mechanism of fractures by counterstroke critically. Grima defined *contrecoup* as an injury inflicted at any point other than that to which the violence was applied: fracture of the cranium at an opposite point—which was often spoken of as if it were the only true counterstroke—

¹ Louis. *Recueil d'observations d'anatomie et de chirurgie pour servir de base à la théorie des lésions de la tête par contre-coup*, etc. 12mo. pp. 385. Paris, 1788. Pp. 13, 37.

² Grima. *Mémoires sur les sujets proposés pour le Prix de l'Académie royale de Chirurgie*. Tome iv. Paris, 1778. Pp. 246–273.

³ Saucerotte. *Ibid.*, pp. 368–438.

⁴ Sabouraut. *Ibid.*, pp. 335–518.

⁵ Chopart. *Ibid.*, pp. 519–562.

⁶ Bazille. *Mem. sur la proposition suivante; Exposer les effets des contrecoups dans les différentes parties du corps, autres que la tête*, etc. *Prix de l'Académie royale de Chirurgie*. Tome iv. pp. 563–633.

This essay was translated and published in English in 1789, in the surgical tracts of the late J. O. Justamond, F. R. S., etc., edited by Mr. William Houlston—4to., London, 1789.

being only one form of it; and he included under his definition injuries of the contents of the cranium without fracture of the bony part. All this, it will be seen from what I have stated above, had been more or less imperfectly laid down long before; but it was not until the epoch of which I am now speaking that it was clearly formulated. Grima insisted upon considering the skull as one piece after the sutures had closed, a very important matter in regard to the mechanism of fractures in it. He also calls attention to the possibility that a fracture attributed to counterstroke has been caused by a fall after a blow, a point in regard to which, as we have seen, Paul of Ægina referred 1200 years before. Grima compared fracture of the cranium by *contrecoup* to that which occurs in a stone-wall, which, when struck at one point, may break at another. He divides *contrecoup* into seven kinds, one being that in which the contents of the skull alone are lacerated. He speaks of Valleriola as having recognized a *contrecoup* by the occurrence of a gangrene at the side opposite to that which had received the blow, and of Bartholini as having drawn the same conclusion from the presence of an abscess. Grima, finally, advises trepanning at the suspected point, when symptoms arise which cannot be accounted for by the local injury, claiming that if it proves useless, it can, at least, do no harm.

Saucerotte adopted practically the same definition of *contrecoup* as did Grima: "A lesion produced by a blow in another place than that which received the blow." He makes eight kinds of counterstroke, one of them involving the diploë alone. In explaining the mechanism of counterstroke, he considers the skull as a solid case, which, in its vertical section, presents the

appearance of a scalene triangle. He dwells upon the varying degrees of thickness and strength in its different parts, and claims that its fractures are due to over-curvation and to flattening. In this he foreshadows a theory of which I shall speak hereafter, as well as in the further statement that when the skull is struck it "undulates" and changes its shape "alternatively." The vibration theory, involved in comparisons of the skull to a wall, as done by Grima, or to a glass or clay vase, which was a very ancient comparison, he rejects. He lays stress on the very important point that the skull contains fluid contents which are extremely incompressible, holding that a blow sets in motion a column which is practically solid and which strikes with great violence the opposite side—a conclusion which contains a fatal error, since the laws of hydrostatics make it clear that such a force is transmitted equally in all directions. Finally, he directs attention to a point which should never be overlooked, namely, a due appreciation of the character and direction of the force which effects the injury. Among his practical conclusions, one is to trepan more boldly than some surgeons think advisable nowadays, and another is to cut into the brain itself in certain cases.

Sabouraut speaks of the skull as a spheroidal case which cannot break without changing its shape. Under the influence of a blow, he says, its diameters lengthen and shorten, and shorten and lengthen alternately—a statement which would appear to be inverted unless it be understood to refer to the diameter perpendicular to the direction of the blow, in which case it fits exactly the theory already alluded to as to be spoken of hereafter. He explains the physics of the skull, as he under-

stands them, quite thoroughly, and acknowledges the difficulty of making a practical application of the information which an understanding of them might be expected to afford.

Chopart describes the skull as an elliptical case, and divides *contrecoup* into eight varieties, similar to those already referred to. He also calls attention to the fractures produced by falls upon the buttocks, knees, or feet, and classes them under the heading of counterstroke.

The essay of David, mentioned together with those we have been citing, is interesting as showing the extent to which in those days the idea of counterstroke was stretched, for it includes a number of fractures which are nowadays attributed to muscular action, as well as injury of the contents of the pelvis, abdomen, and thorax by the concussion due to falls.

In 1773, Mehée de la Touche published a valuable monograph on counterstroke¹ in which the same broad definition of it is given, namely, "a lesion produced by a blow at another point than that which was struck." The opposite point he considers the most frequent seat of counterstroke, that occurring elsewhere he attributes to special weakness of the part which yields. From the consideration of counterstroke he goes on to that of its symptoms, and is led into an interesting discussion of cross-paralysis, in regard to which he records some instructive experiments on dogs. This subject had attracted attention since the earliest times of medicine, and had been very sagaciously studied in the beginning

¹ Mehée de la Touche. *Traité des lésions de la tête par contre-coup*. Small 8vo. pp. xix. 264. Meaux, 1773.

of the 18th century by Parfour de Petit,¹ whose experiments on dogs were of the most interesting and ingenious character.

It was not until the beginning of the present century that I find any noteworthy reference to the mechanism of fractures of the cranium in England, when Sir Charles Bell² compared the movements of the cranium under the influence of a blow to those of a bell, and illustrated his views by an experiment in which he placed two balls inside of, and touching a hoop, one at each pole of the direction of the blow to be applied, and two more outside of, and touching it at the poles of the transverse diameter. On striking the hoop, the two balls in the line of the force are driven toward the centre, while the two balls at the poles of the transverse diameter are driven away from it. This shows that a blow shortens the diameter parallel to the direction of the force and lengthens that one perpendicular to it—another foreshadowing of the theory already referred to and to be described hereafter.

In 1828, Mr., afterward Sir, Benjamin Brodie³ accepted the current theory of counterstroke, and described the fractures caused by the impact of other bones on the cranium.

In 1844, Aran published an exceedingly valuable paper on fractures of the base of the skull,⁴ in which he

¹ Petit. *Nouveau Système du Cerveau*. Extrait des Lettres d'un Médecin des Hôpitaux du Roi à Namur (Parfour de Petit.) In Louis: *Recueil d'observations d'anatomie et de chirurgie pour servir de base à la théorie des lésions de la tête par contre-coup*, etc. 12mo. pp. 385. Paris, 1788.

² Sir Charles Bell. *Surgical Observations*. 2 vols. 8vo. Edinburgh, 1816. Vol. i. pp. 461-489.

³ Brodie, B. C., F.R.S. *Pathological and Surgical Observations relating to Injuries of the Brain*. *Medico-Chirurgical Transactions*, 1828, vol. xiv. pp. 325-423.

⁴ Aran, F. A. *Recherches sur les fractures de la base du crâne*. *Arch. gén. de Méd.*, 4 sér., tome vi. pp. 180-209, 309-347, Paris, 1844.

formulated a theory which has been known by his name ever since. This theory was, that fractures of the base are always connected with fractures of the vault, from which they radiate, following a line within the zone in which the former occurred, and taking a course which corresponds with shortest route to the base. His conclusions are formulated as follows :

1. He never saw a fracture of the base, caused by a blow, without a direct fracture.

2. Fractures of the vault joined the base by "irradiation," and crossed any sutures in their way.

3. They followed the shortest route to the base (the curve of shortest radius).

4. They were ordinarily limited to certain regions (corresponding to the several great fossæ of the cranium), and followed a certain direction.

5. Fractures of the vault sometimes coincide with *independent* fractures of the base ; but only when there is considerable comminution (*ébranlement*) and very multiplied fractures.

These conclusions of Aran rested upon the results of a large number of experiments, upon fresh and dry skulls, by blows with very heavy hammers, and by throwing them down upon a hard pavement, as well as experiments in which he pitched entire bodies down upon their heads after having made the legs rigid by binding them to a strong iron bar. Certain writers have assumed that his experiments numbered one hundred. The only ground which I can find for this assumption is his statement that indirect fractures of the base by irradiation constitute 99 per cent. of the whole number—a statement which furnishes no clear indication as to the number of his experiments.

In 1847, Guthrie¹ published a monograph on injuries of the head, which is unsurpassed in the English language, in which he gives an excellent *résumé* of the history of various sorts of fractures of the cranium. Among them he speaks of counterstroke, the occurrence of which from temporal to temporal, or from parietal to parietal, he doubts, but says that fracture of the base from blows on the vertex or occiput are among the commonest accidents of surgery. Except for an uninterpreted reference to a statement of Chopart (*q. v.*), he expresses no opinion whatever as to their mechanism.

In 1853 was published, in *Guy's Hospital Reports*, a first instalment of Mr. Hilton's sagacious lectures on the cranium,² which was followed, in 1855, by their publication entire in a separate volume, by Dr. Pavy, after their revision by Mr. Hilton himself.³

In these lectures Mr. Hilton explains fractures of the skull upon the "vibration-theory," and speaks of the posterior clinoid processes and the extremities of the petrous bone as points to which vibrations are conducted, and where they are transmitted to the cerebro-spinal fluid, thus being "interrupted or lost before reaching the cerebral tissues," etc. The fallacy of this conclusion I shall have to consider hereafter, citing Mr. Hilton's opinions here for their historical interest.

In 1854 the keynote to a new theory of indirect

¹ Guthrie, G. J. On Injuries of the Head, etc. 4to. pp. vi. 155. London, 1847.

² Hilton, John. Notes on the Development and Design of Certain Portions of the Cranium. Four Lectures by John Hilton, F.R.S. Collected by F. W. Pavy, M.B. *Guy's Hospital Reports*, 1853, pp. 357-400.

³ Hilton. Notes on Some of the Developmental and Functional Relations of Certain Portions of the Cranium. Selected by Frederick William Pavy, M.D., London, from the Lectures on Anatomy, delivered at Guy's Hospital, by John Hilton, F.R.S. 8vo. pp. 93, with 9 plates. London, 1855.

fractures of the skull—which had, however, as we have seen, been foreshadowed much earlier by certain observers—was struck in Germany by experiments made by Bruns,¹ of Tübingen, to determine the elasticity of the cranium.

In 1858, Mr. Prescott Hewett published a series of lectures on the anatomy, injuries, and diseases of the head, in which is contained an exceedingly full and able discussion of fractures of the cranium. He thought fractures by *contrecoup* to be rare, though he says that “indirect fractures” of the base are very common. As to the general law which governs the location and extent of fractures of the cranium, he accepts the views of Aran.²

In 1864, Chauvel published a thesis on fractures of the cranium,³ founded upon a careful study of its anatomy, in which he laid great stress upon the elasticity of the skull, and described the “vibrations” produced by a blow, as the repeated and alternating shortening of the prime axis and lengthening of the transverse axis. He called attention to the fact that the petrous bone, although the hardest in the cranium, is the one most frequently fractured. He described three kinds of fractures: 1, direct; 2, contra-direct; 3, indirect. The first kind is simple enough. The second occurs opposite to the point struck, and he offered no explanation for it, except the comparison of fractures caused by the spinal column to the manner in which the handle is driven into the head

¹ Bruns. Die chirurgischen Krankheiten und Verletzungen des Gehirns, etc. Tübingen, 1854.

² Hewett, Prescott. Lectures on the Anatomy, Injuries, and Diseases of the Head. Med. Times and Gazette, 1858, vol. xvii. pp. 311, 312.

³ Chauvel, F. Essai sur les fractures du crâne. Thèse de Paris, 1864.

of a hammer by striking the remote end of the handle against some resisting body. The third form of fracture he defined as that occurring between the point struck and that directly opposite. This he found in 11 out of 60 fractures.

In 1872, Schwartz analyzed 115 cases, in most of which the history was very incomplete, and he found fracture of the base alone, without fissure of the convexity, only 7 times. He found about 39 per cent. of fractures limited to the zones described by Aran and Hewett; while in over 60 per cent. this regularity was wanting. [Hewett's figures were about the same, though his conclusions were different.] This is one of the most important features of his investigations. Another is that a study of the fractures he had analyzed showed that the petrous bone was fractured in 66 out of 115 cases; and that force applied to the side of the head caused fractures somewhat parallel to the axis of the bone, while force applied to the occiput, or forehead, or vertex, caused fractures transverse to the axis.¹ This was an important contribution to the accumulating material for a new consideration of the mechanism of indirect fractures of the skull, as we shall see hereafter.

In 1873, Félizet published an elaborate illustrated monograph on the subject of fractures of the cranium, which, with the paper of Aran, may be regarded as among the most important contributions to the literature of the subject up to that time.² He regards this as a solid case, of a spheroidal shape, but claims that its internal

¹ Schwartz, Arnold. Zur statistik der Fracturen der Schädelbasis. In. Diss. 8vo. pp. 52. Dorpat, 1872.

² Félizet, G. Recherches anatomiques et expérimentales sur les fractures du crâne. 8vo. pp. 167. Paris, 1873.

configuration renders inaccurate a comparison of it to any geometrical figure whatever. By experiment he demonstrated that the dura mater makes the skull where it is attached more resistant to fractures caused by flattening its curve. Experimenting with a billiard ball let fall from a height, he found that its equator was increased, that this increase was greater in a direction at right angles to its fibres than in a direction parallel to them. The result was an ellipsoidal equator, and when a fracture occurred, this crossed the long diameter at right angles (p. 72). He unwittingly paraphrases the theory to which I have several times alluded, and which I shall soon consider, in saying, "We know that a fracture results from depression of the curved surface situated between two resisting pieces, and we know, also, that every effort tending to depress this curve divides into two forces, the one a driving force (*force de tassement*), which acts on the axis, or near to it, of the supporting walls; the other, a disruptive force (*force de glissement*), which acts transversely to them, and tends to separate the two extremities of these pieces" (p. 108). Again (p. 139), he compares the separation of sutures, the result of blows, to that which is effected in anatomical preparations by filling the skull with dry peas, and then soaking them, so that by swelling they tear the skull apart. He declares that there is a perfect analogy between this and what he calls the "*grand fracas*" (grand smash), in which he says "the bones, compressed over a large surface, rock (*basculent*), and this rocking movement sets up violently a dragging force perpendicular to the plane of the surface of union of the bones of the cranium." As we shall see hereafter, this is the same as saying that a force which depresses an elastic curved figure, will

enlarge its diameter, and be converted into a disruptive force acting at right angles (perpendicular) to the meridian. Herein Félizet comes near to the theory which the Germans call the "Berstungs" theory, although he does not quite reach it, and may perhaps, even now, not see his statements to be so strong a confirmation of it as they appear to me to be.

The term "*contrecoup*" Félizet rejects, and would adopt that of M. Beau, of Brest, who called indirect fractures "mediate." Félizet compares the mechanism of these fractures to those produced by a blow upon a wedge or a chisel. The part broken, he holds, is directly struck by another part, which, in its turn, received a blow and transmitted it. Yet he admits that, very rarely, these fractures by *contrecoup* do occur (p. 156). He divides fractures of the cranium into direct, indirect, and mixed. Indirect fractures include those which are independent. In respect to the application of the violence which causes them, fractures may be divided into immediate and mediate (pp. 159, 160). His conclusions may be briefly stated as follows: all fractures not immediately limited to the point of impact follow certain definite routes, to which they are restricted by the added strength of certain parts of the skull, which depends upon the presence of certain "*murs boutants*" (buttresses): the petrous bones, the orbito-sphenoid prominences, the occipital protuberance, and the naso-frontal protuberance. The basilar process and the antero-lateral parts of the occipital bone remain intact amid all fissures and constitute a "centre of resistance." The vibration theory, he says, is disproved by experiments, the fundamental phenomenon is a violent flattening of part of the vault, and a separation of the resisting portions (*pièces de résistance*)

which support it. When the violence is perpendicular to the surface of the cranium, fractures radiate directly to the base. In this, it will be seen, Félizet agrees with Aran. Finally, he admits that there are fractures, called by "*contrecoup*," the mechanism of which escapes us completely (pp. 161-164).

The opinions of Félizet are founded upon a careful analysis of a number of pathological specimens and upon a number of experiments upon fresh skulls. The value of his work can be appreciated only after a thorough study of it. The result of it was to bring him to a conclusion which may be succinctly stated as that indirect fractures are due to a disruption by splitting. There can be no doubt that the course of a fracture will be determined to a considerable extent by the reinforcements which the skull has, in certain places, from its buttresses (*murs boutants*); but, as we shall see hereafter, these very buttresses are often broken both transversely and longitudinally, and Félizet's centre of resistance is by no means a centre of immunity, but an exceedingly frequent seat of fracture.

A few years later—for events now crowd upon each other in the history of fractures of the cranium—Baum¹ opposed the vibration theory, and made some experiments by strewing sand on a skull and applying a vibrating tuning-fork to it. From these experiments he concluded that vibrations were restricted by surrounding less elastic parts, like the vibrations of a drum-head. The petrous bone, however, he concluded, owing to its anatomical structure and relations, vibrates like a rod held by one end in a vice. He refers to Weber's

¹ Baum, W. Beiträge zur Lehre von den indirecten Schädelfracturen. Langenbeck's Archiv f. klin. Chir., Bd. xix. S. 381-399, 1876.

wave theory, and concludes that blows upon the skull do not furnish the conditions of repeated impulses which produce a high vibratory action. By compression of a few skulls in a suitable frame he got results which correspond to those of later German experimenters, who adopted the "bursting" theory.

In 1878, P. Bruns attributed indirect fractures to the elasticity of the skull, as described by v. Bruns in 1854, and explained the frequent occurrence of these fractures in the base of the skull by the fact that this is the weakest and most fragile part of it.¹

In the same year, Perrin made some very instructive experiments, in which he attempted to imitate the usual conditions of the skull by protecting it with an elastic cushion of cotton wadding or of caoutchouc and then throwing it upon a stone pavement, or by putting the cushion on the pavement itself. He always got direct fractures by blows, and by precipitating the skull he usually got indirect fractures. He showed typical specimens to the Société de Chirurgie, in all of which the fractures were indirect and meridional, and in some interesting cases the vitreous alone was involved in certain places. He found that blows on the vertex or occiput usually cause fractures by contrecoup (which he defines as fractures occurring at a place other than that struck), direct fractures being rare exceptions; while blows on the forehead, the parietals, or the temporal bones, rarely cause any but direct fractures.²

In 1880, Bergmann published another valuable con-

¹ Bruns, P. Die allgemeine Lehre von den Knochenbrüchen. Deutsche Chirurgie, Lief. 27, 1 Hälfte.

² Perrin, Maurice. Les fractures du crâne par contre-coup. Bull. et mem. de la Soc. de Chir., 1878, pp. 128-136.

tribution to this subject.¹ He compared the elastic conditions of the skull to those of the thorax, which, when compressed or struck in one part, breaks in another. He also compares the mechanism of fractures of the skull to the bursting of the eyeball under pressure, referring to Arlt's demonstration², that when compressed the eyeball bursts in the equator. Fractures from severe blows, he believes, follow this law; those dependent upon moderate force follow the law laid down by Félizet. He analyzes the statistics of Prescott Hewett and of Schwartz, already referred to, and finds that a majority of their cases did not follow Aran's law. He calls attention to the importance of duly estimating the variations in amount, direction, and velocity of the force applied to the skull, and the support afforded by strengthening bones of the skull and face. He cites Baum (whom I have cited) as refuting the vibration theory, and seems to have the idea that indirect fractures of the skull are to be attributed to a disruptive force, and not to a propagation of vibrations.

In 1880, Messerer³ conducted a series of experiments which demonstrated more accurately than had ever been done before the elasticity of the cranium, and which made clear the fact that when the skull is compressed in one axis, the circumference at right angles to it is enlarged.

In 1881, Nicolai Hermann published an inaugural dissertation on fractures of the base of the skull, in

¹ Bergmann. *Die Lehre von den Kopfverletzungen*. Deutsche Chirurgie (Billroth and Luecke), Lief. 30. Stuttgart, 1880.

² Arlt. *Die Verletzungen des Auges mit besonderer Rücksicht auf deren gerichtsärztliche Würdigung*. 1875. S. ii.

³ Messerer. *Ueber Elasticität und Festigkeit der menschlichen Knochen* Stuttgart, 1880. Cited by V. Wahl, *q. v.*

which, besides an analysis of 75 cases gathered from various sources, he gives an account of 17 experiments in which he compressed the skull in longitudinal, transverse, and diagonal directions, until it broke. His experiments always resulted in a fracture parallel to the direction of the compressing force. He believes that fracture always begins at one of the points compressed and travels away from it. By analyzing the cases he had collected he concluded that they supported his deductions from experiments.¹ It seems to me that some of his figures show plainly that the fissures must have begun at the middle and travelled both ways.

In the same year Julius Schranz published an account of 34 experiments upon skulls, some (13) from which the vault had been removed, but the most of them entire, in which he endeavored to imitate the conditions in which fractures are caused by different sorts of violence. The experiments were interesting and instructive. The great majority of the fractures he produced were splitting fractures, and *not* immediately connected with the point to which the violence was applied. In a considerable number isolated pieces of the vitreous table were split off, or the dorsum ephippii. These (and other indirect fractures), he says, can only be explained by the vibration theory. A curious result of his experiments was that the brain was injured only once, and the dura mater separated from the bone only three times!²

But it remained for von Wahl,³ in 1883, to utilize

¹ Hermann, Nicolai. Experimentelle und casuistische Studien über Fracturen der Schädelbasis. Inaug. Diss. 8vo. pp. 67, 23 plates. Dorpat, 1881.

² Schranz, Julius. Untersuchungen über das Entstehen von Schädelbrüchen. Mediz. Jahrbücher (Wien), 1881, pp. 291-314, with 5 lithographic plates.

³ Wahl, Ed. von. Ueber Fracturen der Schädelbasis. Volkmann's Sammlung klin. Vorträge, No. 228. 8vo. pp. 26. Leipzig, 1883.

the material which had been recently gathering, and to formulate unequivocally the theory that fractures of the skull may be divided into: 1, crushing fractures, in which the line of fracture runs at right angles to the axis of the force applied; and, 2, bursting fractures, in which the lines of fracture are parallel to the axis of the force which gives rise to them, and which begin, in the words of Messerer, at some point in a line which, like the equator, in relation to the poles of the earth, circumscribes the hollow figure in a plane equally distant from both points of compression. He claims that, in compression of the skull—which may be gradual, as in a vice, or sudden, as when effected by a fall or blow—its elasticity, *in toto*, comes into play, and while its diameter which is parallel to the force applied is shortened, its diameters which lie at right angles to this are lengthened. The result is, that indirect fractures run in lines which we may describe as meridional. His conclusions rest not only on theoretical considerations and a review of the testimony and opinions of others, but also upon his own clinical experience, and a series of ingenious experiments, which are fully described and beautifully illustrated in his monograph, a careful study of which may, without injustice, be said to be indispensable to one who would form a correct opinion upon the subject of which it treats.

In 1884, Dr. Nancrede, of this city, published an elaborate and valuable paper on "Injuries of the Head,"¹ in which he adopts the vibration theory, and supports his opinions with some interesting anatomical and

¹ Nancrede, Charles B. Injuries of the Head. International Encyclopædia of Surgery. Edited by John Ashhurst, Jr., M.D., etc. New York, 1884. Vol. v. pp. 1-109.

physical considerations. He regards the base as a stronger part of the cranium than the vault (pp. 30 and 32), speaks of the brain as lying on a water-bed (p. 31), and describes vibrations of the bones as traveling by the nearest "anatomical" route to the base, there to be discharged, like electricity, at certain points—the ends of the petrous bones and the clinoid processes—into tissues which are non-conductors of vibration. He also calls attention to the important influence which the position of the head has upon the direction in which a force applied to the condyles will be conducted. In a very interesting case, which he cites from his own experience, there was a separation of the masto-occipital suture, which he says was forced apart "as if from within."

In 1884, Messerer published a second and most admirable paper on fractures of the cranium,¹ in which he gives a description and analysis of eighty-two experiments on fresh skulls, sometimes on entire cadavers. His experiments included accurately regulated blows upon skulls, detached or resting on the spinal column, and falls of the skull upon a hard base. These experiments completely refute the laws of Aran as well as those of Félizet, and seem to show conclusively that indirect fractures of the skull are dependent upon separation of the meridians caused by the depression produced at the point of contact by a blow.

Finally, our sketch of the history of this subject is brought down to the present year by a reference to the

¹ Messerer, Otto. *Experimentelle Untersuchungen über Schädelbrüche*. 8vo. pp. 36, with 8 plates. München, 1884.

interesting and beautifully illustrated paper of Greder, published in the early part of 1885.¹

The experiments of Greder were made upon skulls connected with the trunk and still covered with their integuments and containing the brain, by blows with a weight of 6400–7650 grammes (about 12–15 pounds). After a large number of these experiments, some of which were most ingeniously varied, Greder comes to the conclusion that solutions of continuity of the base of the skull are to be regarded as the result of bursting; that the direction of all fissures is parallel to that of the force causing them; that the extension of a fissure is dependent upon so many intercurrent conditions peculiar to each skull, that it can at most be only suspected from the intensity of the violence (p. 509). As to the point at which the burst begins, he holds that it is not always in the equatorial line, nor always at the point of impact, but at that point where resistance to the disruptive force is least. This will happen, he thinks, in the majority of cases, in the equator or in its neighborhood (p. 506).

THE ELASTIC PROPERTIES OF THE SKULL.

From the preceding sketch, it will be seen that those who have thoroughly investigated the mechanism of indirect fractures of the skull have been led to conclusions which establish a great importance for its elastic properties. These properties, as we have seen, were first clearly enunciated about the middle of the last century by Saucerotte, Sabouraut, and Chopart, in their

¹ Greder, Wilhelm. Experimentelle Untersuchungen über Schädelbasisbrüche. Deutsche Zeitschrift für Chirurgie, Bd. xxi., 5 und 6 Hefte, 9 März, 1885, S. 491–510, tafeln vii.–xiv.

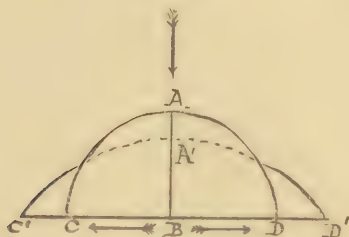
essays for the prize of the Academy of Surgery of Paris. In the beginning of this century, Sir Charles Bell illustrated them by an ingenious physical experiment. In 1854, von Bruns demonstrated them by a series of experiments which only required multiplication and variation to confirm what an important part the elasticity of the skull plays in the production of indirect fractures. Since then, almost innumerable experiments and studies of specimens of fractures of the skull have coöperated to establish the conviction that, with certain exceptions, the mechanism of indirect fractures of the skull may reasonably be explained according to what the Germans call the "bursting" theory—that is, to the conversion of direct depressing force into an indirect disruptive force, brought about by a shortening of the axis parallel to the direction of the force and a complementary lengthening of the axes at right angles to the former. A mass of evidence in support of this view is now accessible to any one who cares to examine it. It would not be possible to lay it all before you; so I shall select what I think most suitable to this occasion, and ask your attention to certain results obtained by Messerer, whose experiments in this connection have been very numerous and may be regarded as typical. In doing this, I intend no reflection upon the admirable work of Aran, von Bruns, Félizet, Baum, Perrin, Hermann, Schranz, von Wahl, and Greder, which must be studied to be sufficiently appreciated.

The experiments of Messerer can be analyzed so as to throw a great deal of light upon the physical properties of the skull, revealing the parts in which it is strongest, and those in which it is weakest.

But, in order to understand their significance, we

must have a clear idea of the mechanism by which, in a hollow case, the shape of which has a general resemblance to that of a spheroid or ellipsoid, a compressing force is converted into a disruptive force. It will be readily seen that when an elastic spheroid is compressed in any diameter, all the diameters lying at right angles to this—that is to say, in planes parallel to that of the equator—must be elongated. The experiment of pressing on the convex side of a bow, the ends of which rest on the ground, will illustrate what takes place in every chord of every arc that is depressed. (See Fig. 1.)

FIG. 1.

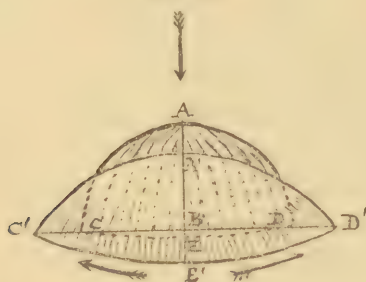


When a force is applied to A so as to shorten the axis AB to A'B, the axis CD will be lengthened to C'D', and the compressing force in the line AB is converted into a disruptive force acting at right angles to this—that is, in the line CD.

It is equally clear that the elongation of the diameters lying in any plane will elongate the circumference of this plane, because a circumference of longer radius is longer than a circumference of shorter radius. As a result of this elongation of the circumferences parallel to the equator in any spheroid or ellipsoid, the meridians passing from pole to pole will be separated in a direct ratio to the extension of the different diameters and circumferences. This operation is illustrated whenever an

umbrella is raised. (See Fig. 2.) As a consequence of the separation of the meridians in a hollow sphere or ellipse, particles which before occupied a certain space between two meridians, will be compelled to separate in order to occupy the increased space between the meridians. The consequence will be that, in every case such as we have supposed, there will be a struggle between the cohesion of the particles and the disruptive force due to the separation of the meridians, and whenever the disruptive

FIG. 2.



When in a spheroid a force is applied to A so as to shorten the axis AB to A'B, all the axes at right angles to it are lengthened, and the circumference of any plane in which they lie will be lengthened, as CED to C'E'D', and the meridians passing round the spheroid will be separated. Thus the direct depressing force is converted into a disruptive force acting at right angles to it.

force overpowers the cohesion of the particles lying along and between two of the meridians, a solution of continuity will take place. The disruptive force will be at a maximum at the equator, but the same conditions of disruptive force opposed to cohesion will be found in different proportions in every line parallel to the equator. As a result, in a perfect sphere with homogeneous walls such a solution of continuity would naturally begin at the geometrical equator and extend equally and simultaneously in opposite directions in a

meridional line toward the poles. But in a spheroid or ellipsoid not regular in shape, and with walls varying in strength in different parts, the result would be modified by these variations. This is exactly what we find in the case of the skull, which, while bearing a certain resemblance to an ellipsoid, does so in only a modified way, and can only be expected to exemplify the law just stated subject to modifications due to its own peculiarities.

With this in mind, let us see what the experiments of Messerer show. Messerer found that the skull burst in the base under an average pressure of 650 kilogrammes applied in a longitudinal direction, and under an average pressure of 520 kilogrammes applied in a transverse direction. From this we may draw two very important deductions. First, because the burst took place in the base:

Corollary I. The cohesive power of the base of the skull is less than that of the vault.

Second, because the skull burst under a pressure of 529 kilogrammes applied transversely, and under a pressure of 650 kilogrammes applied longitudinally:

Corollary II. Cohesion is less in the coronal zone of the skull than in the sagittal zone—that is to say, the skull is less able to resist a disruptive force due to blows upon the vertex or sides in the coronal zone than it is to resist a similar force caused by blows applied to the forehead or occiput. This is not only a fair inference from the experiments of Messerer, but it also accords with clinical observation.

Messerer found again that compression of the skull in a transverse direction, with a force of 520 kilogrammes, diminished the transverse diameter 4.4 millimetres; and

that compression in a longitudinal direction, with a force of 650 kilogrammes, diminished the longitudinal diameter only 2.7 millimetres. From this we may deduce

Corollary III. The skull is more compressible in the transverse diameter than in the longitudinal diameter. (This fact tends to strengthen the deduction of Corollary II.)

Messerer found, also, that compression of the skull in the transverse diameter, with a force of 520 kilogrammes, increased the longitudinal diameter 0.4 millimetre, and the perpendicular diameter 0.6 millimetre. From this we may deduce

Corollary IV. The skull is more extensible in the perpendicular diameter than in the longitudinal diameter of the sagittal zone. The natural inference from this corollary is that, under the influence of a force applied to the sides of the head a fracture which would naturally begin in some point in the sagittal zone, will begin in that part of it which is intercepted by the perpendicular diameter more readily than in that part of it which is intercepted by the longitudinal diameter—that is to say, at the base or vertex rather than at the forehead or occiput. We have already seen (Corollary I.) that the cohesion of the skull is less at the base than in the vault, therefore: of the two points just indicated, the base is that of election. Here, again, clinical observation supports our deduction.

Messerer found, further, that compression of the skull in the longitudinal diameter with a force of 650 kilogrammes increased the transverse diameter 0.6 millimetre, and the perpendicular diameter 0.1 millimetre. From this we may deduce

Corollary V. The skull is more extensible in the transverse diameter than in the perpendicular diameter of the

coronal zone. (This is the converse of Corollary III.) The natural inference from this corollary is that, under the influence of force applied to the forehead or occiput, a fracture which would naturally begin at some point in the coronal zone will begin in that part of it which is intercepted by the transverse diameter more readily than in that part of it which is intercepted by the perpendicular diameter—that is, at the sides rather than at the base or vertex. We have already seen (Corollary I.) that cohesion is less in the base than in the vault; therefore, a fracture which, for the reasons just stated, would naturally begin at the side of the skull would be more likely to occur near the base than near the vertex. In estimating this probability it may also be borne in mind that the horizontal equator of the skull lies nearer to the base than to the vertex, the curvature of the former being much less than that of the latter: so that the point of election for the fractures we are now discussing would naturally lie low down on the side of the skull. This deduction also is supported by clinical observation.

Messerer found, again, that compression of the skull in the transverse diameter, with a force of 520 kilogrammes, increased the longitudinal diameter 0.4 millimetre and the perpendicular diameter 0.6 millimetre; and that compression of the skull in the longitudinal diameter with a force of 650 kilogrammes, increased the transverse diameter 0.6 millimetre and the perpendicular diameter 0.1 millimetre. From this we may deduce

Corollary VI. The skull is more extensible along the sagittal equator than it is along the coronal equator. We have already seen (Corollary III.) that the skull is more compressible in the transverse diameter than it is in the longitudinal diameter. It is, therefore, seen that the equa-

tor along which the skull is more extensible (the sagittal) is that one the plane of which is cut at right angles by the diameter in which it is more compressible (the transverse), and *vice versa*; which furnishes in the skull a demonstration not only of the elongation of the equator which is produced by depression of the poles of a spheroid, but also of the direct ratio of this elongation to the depression. Furthermore, it appears from the observation of Messerer just cited, that a smaller force applied to the skull in a transverse direction will produce a greater elongation of the corresponding equator than will be produced by the application of a decidedly greater force in a longitudinal direction. From this we may draw the deduction that force applied to the side of the head is more likely to produce a fracture crossing the sagittal equator than force applied to the forehead or occiput is to cause a fracture crossing the coronal equator. This deduction is in accord with the results of Messerer's experiments, in which the skull burst under a pressure of 520 kilogrammes applied in a transverse direction, and only under a force of 650 kilogrammes applied in a longitudinal direction. It is also in accord with clinical observation.

We have now analyzed Messerer's experiments so as to ascertain the points of election for disruptive fractures which may occur in (that is, across) two of the principal equators of the skull, the sagittal and the coronal. It is not possible to discover in the same way the points of election in the horizontal equator of the skull; for Messerer found that compression of the skull in the vertical direction, between the vertex and the spinal column, led to a direct driving in of the base under so small a pressure as 270 kilogrammes.

The results of our analysis of these experiments may be summarized as follows: 1. Bursting fractures are more likely to occur at the base of the skull than in the vault. 2. Force applied to the side of the head may be expected to produce a bursting fracture crossing the sagittal equator. Such a fracture is more likely to occur in the base than at the vertex. 3. Force applied to the forehead or occiput may be expected to produce a bursting fracture crossing the coronal equator. Such a fracture is likely to occur in the temporo-parietal region, and nearer to the base than to the vertex. 4. Force applied to the vertex or base of the skull may be expected to produce a fracture at the base.¹

ANATOMICAL PECULIARITIES OF THE SKULL.

Having now briefly considered the elastic properties of the skull, let us next study its anatomical peculiarities, which, as I have already pointed out, may be expected to modify the results which might be expected if the shape of the skull were regular and its thickness uniform. These peculiarities must be given due consideration if we would avoid the error of applying too rigorously the bursting theory; at the same time, they must not be overestimated. This was the error of Félizet, who was right in attaching great importance to the architectonic conditions of the skull, but who was mistaken in supposing that his buttresses and centre of resistance would stand firm against all or most fractures.

¹ It may be worth while to call attention to the fact that there is no essential difference between a blow applied directly upon the vault or side of the skull and one transmitted through the spinal column by a fall upon the feet or buttocks.

So Aran, before him, was right in supposing that fractures starting in one fossa of the skull would often be limited to that fossa; but he erred in supposing this could be stated as a general law. Both of these theories depended upon what we may call the accidents of fractures of the skull; the essential, I believe—and the future may show that this view may be applied too rigorously—is to be found in the elastic properties of the skull, as revealed not only by the experiments of von Bruns and of his German followers, but also by those of Aran and of Félizet themselves, and by the investigations of others before their time, to whom allusion has already been made in the historical sketch at the beginning of this paper.

The thinnest portions of the various bones of the skull are as follows:

In the frontal bone. The walls of the frontal sinuses; the orbital plates; the temporal portions; and sometimes on both sides of the crest for the attachment of the falx cerebri.

In the ethmoid bone. The horizontal plate. (The other parts of the bone may be regarded as outside of the true cranial case.)

In the sphenoid bone. The orbital portion of the greater wings, and the walls of the sphenoidal sinuses. The basilar portion of this bone has a deceptive appearance of strength, on account of its thickness; but on section it will be seen to be of such open cancellated structure that it is not surprising to find that it is very often fractured.

In the parietal bones. The lower border, just above the parieto-squamosal suture, and both of the inferior angles.

In the occipital bone. The floor of the cerebellar fossæ; and, to a less extent, the floor of the posterior cerebral fossæ.

In the temporal bones. I take these bones last because they present some extremely interesting anatomical peculiarities, the importance of which I have not found dwelt upon as I think it ought to be. The thinness of the squamous plates is too familiar to need more than mention. But the temporal bone is also often very thin over the cotyloid depression for the head of the inferior maxilla. The mastoid portion is also sometimes occupied by such large open spaces as materially to weaken its walls. The petrous portion does not, on section, present everywhere that solid and rocky appearance to which it owes its name, and which it only partly deserves. The roof of the external auditory meatus is sometimes very thin, in a line parallel to and anterior to the superior ridge of the bone. The floor of this canal is also comparatively thin. The plate of vitreous which covers the anterior inclined plane of the bone is often a mere shell over the promontory above the superior semicircular canal, and further back, in front of the groove for the superior petrosal sinus, it overlies a mass of honeycombed cancellated tissue which communicates with the large cells of the mastoid process. These facts explain the many fractures which are found to run parallel to the crest of this bone, and which have often been wondered at. In like manner, the curious course which a fracture sometimes takes at right angles to the main axis of the petrous bone may be understood when we study the channels and excavations belonging to the middle and internal ear, the

internal auditory meatus, the carotid canal, the groove for the inferior petrosal sinus, and the jugular foramen.

These are some of the weak points of the bones of the skull. Others might be mentioned; as, for example, the antero-lateral rim of the foramen magnum, which, in some cases, is very porous, and far from so strong as its thickness would indicate. It will be noticed that all of these thin parts of the skull lie in or near the base, and clinical observation shows that they are very frequently the seat of fracture.

There are a few other anatomical peculiarities of the skull to which I would like to call your attention before I leave a part of our subject which might well occupy much more time than we can spare it. First, in regard to the posterior clinoid processes. It was long a matter entirely unexplained that violence done to the skull was followed by no fracture, except one breaking off the posterior clinoid processes of the sphenoid bone. But the explanation is easy enough if we accept the "bursting theory," and recognize the fact that the tentorium cerebelli is attached in front to these processes, and that when the long diameter of the skull is increased the tense tentorium holds back with an unyielding strain and tears these processes from their attachments to the rest of the bone. In this we have both a full explanation of the mechanism of these fractures and a beautiful confirmation of the "bursting theory" of indirect fractures of the skull.

Again, let me call your attention to the peculiar conditions of the basi-sphenoid and petrous bones. These bones are never, I believe, united by bony union or close-fitting dentations, like the other bones of the skull. Their adjacent surfaces are simply applied

against each other and united by a membranous or ligamentous band. The plane in which these bones articulate is such that the basi-sphenoid is placed like a wedge between the apices of the two petrous bones. As a consequence, any force, like a blow on the vertex, driving the cranium down upon the spinal column, or a fall upon the buttocks or feet, driving the spinal column up against the cranium, will have the effect of forcing the wedge-shaped basi-sphenoid upward and forward between the two rigid petrous bones, with the frequent result of knocking off one or both of the apices of the latter. This form of fracture is another which has excited much surprise and some fanciful explanations; but, in the light of what has just been stated, it seems to me to be quite comprehensible.

Finally, I have been struck by the fact that certain peculiar fractures of the base of the skull seem to have been due to support of a segment of the occipital bone furnished by the inclination upward and outward of the articular surfaces of the atlas, which embrace the condyles of the occipital bone and restrain it from rupture to such an extent that a fissure will pass on both sides of the protected region rather than through it. This form of fracture I illustrate by a beautiful specimen taken from the Mütter Museum of this College.

ARCHITECTONIC PECULIARITIES OF THE SKULL.

I cannot now do more than allude to the general oval shape of the skull, its various curves, arches, and buttresses, the comparatively even shape and homogeneous character of the vault, and the irregular shape and varying thickness and thinness of the base, with its promi-

nences and depressions, its channels and its so-called sinuses. These are too complex to be detailed here, and too familiar to all to make this necessary. But I would call your attention to what Félizet has laid so much stress upon, the reinforcement of certain regions, as at the junction of the greater wings of the sphenoid bone with the frontal and temporal bones, and of the petrous portion of the temporal bones with the parietals; at the ridge for the attachment of the longitudinal and lateral sinuses within the skull and at those for the attachment of muscles at the back of the head, which vary in importance in different individuals. In addition, we may well bear in mind the comparative roundness of the vault and flatness of the base, and the wedge-like insertion of the lower borders of the parietal bones between the bevelled upper edges of the squamous bones, and the projection of the ends of the petrous bones against the basi-sphenoid, of which I have already spoken in detail. For most of the points one may consult the works on general and special anatomy, or, better still, the skull itself. They all must be considered in studying variations from the result to be expected from the application of any given theory in regard to the mechanism of fractures of the skull, although, as I have said, they need not be expected to controvert any law of general applicability.

INFLUENCE OF THE SOFT PARTS AND CONTENTS OF THE SKULL.

This is another portion of the study of fractures of the skull to which more time ought to be devoted than we can spare now. In a general way, it may be said

that the external and internal coverings of the skull—the dura mater and the pericranium, with the muscles, fasciæ, and skin—tend not only to deaden vibrations to such an extent that it is hard to know how to understand many expressions of those who have accepted what is known as the “vibration theory,” but also to limit to a moderate extent the changes in shape which the skull may undergo, according to the “bursting theory.” The action of the muscles must also be considered of importance, as exemplified in such involuntary and spasmodic contractions as prove sufficient of themselves to break other bones, and which may have more effect here than has yet been suspected. Let us imagine, for example, what might be the effect of a spasmodic contraction of the erector mass at the back of the head when a sudden blow comes upon the anterior part of the vertex, tending to flex the head. I wish it were possible to go further into this inviting field of investigation.

As to the contents of the skull, we have seen that Fabricius ab Aquapendente attributed fractures by counterstroke to the effort of the air, which he supposed the skull to contain, to escape from its cavity. We know better than this; but it does not seem needless to call attention to the fact that the skull is filled with a much more incompressible material than air. In fact, the brain and its membranes, with the surrounding fluid, completely fill the skull with one of the most incompressible materials of which we have any knowledge. Under the influence of a blow, this material tends to increase the disruptive force, according to the well-known laws of hydrostatics. As a full cask may be burst by a blow, so there can be no doubt the skull may

likewise be burst. The statements often made, which affirm or imply that the skull and its contents can be compared to a water-bed, are utterly erroneous. The fluid contained in the cranium, in a state of health, is far too little to justify any such comparison. Besides which, it is contained in a firm, unyielding case; while it is indispensable to a water-bed that its walls shall be soft and yielding. It has also been intimated—and so able a man as Mr. Hilton thought he had demonstrated—that displacement of the cerebro-spinal fluid could be regarded as a protective against injury when the skull was struck. Mr. Hilton's experiment was not free from an important source of error, and one who studies carefully the anatomical peculiarities of the cerebro-spinal axis must see, I think, that there is only one way for compensatory diminution in the contents of the skull to take place, namely, by displacement of its contained blood through its natural channels. This displacement can and does take place when time is afforded for the process, as in the case of a growing tumor; but the rapidity with which a blow tends to diminish the capacity of the cranium far outstrips the speed with which the blood can escape; so that, as a matter of fact, the skull and its contents may be regarded as the very opposite of a water-bed, and more like a cask filled with fluid which may burst under a sudden increase of the pressure upon the inside of its walls. This fact is established not only by a correct knowledge of the physical conditions of the cerebro-spinal axis, but also by experiments and observations which I cannot stop to mention now.

STUDY OF CASES.

A great difficulty confronts at the outset one who tries to discover in how far the study of actual fractures of the skull will bear out any theory in regard to their mechanism which seems plausible. The difficulty depends upon the difference between the known factors in an experiment and the unknown factors in an accident. It is often impossible, in the case of a fracture of the skull, to ascertain exactly the amount and direction of the force, the point to which it was applied, and the conditions of resistance or evasion of the whole cranial box. This consideration should lead to a modest and reserved fitting of what seem to be facts to any theory. Nevertheless, nothing can be learned by standing still; and we may, if not overconfident, make some advance in knowledge by testing a theory by an observation of what actually takes place. With this object in view, I have examined the published accounts of a very large number of cases of fracture of the skull, and I have collected more than a hundred (119) in which the details seem to me to be sufficient to warrant an approximative estimate as to the conditions under which the fracture occurred, and as to the results produced. I cannot go over the records of these cases in detail, but I now show you drawings of all of the fractures, each accompanied by a reference to the source from which I have obtained it, and such verbal explanations as will, I trust, enable you to form some opinion as to the amount of support they can be credited with affording to the "bursting theory" which I have already described and endeavored to explain. In presenting

these drawings to your attention, I must warn you against certain sources of error in them. The first depends upon the imperfection of the great majority—I might almost say of all—of the records from which they have been made up; the second depends upon the great difficulty of representing upon a flat surface what may be gathered from a verbal description of so complex and intricate a thing as a fracture of the skull.

In addition to the drawings representing each case of fracture by itself, I show you one in which I have transferred to a single diagram all the fracture lines falling within the base of the skull. I do this to indicate, if it be possible, where fractures most frequently occur, and also to make clear the fact that the parts which Félizet has assumed to have peculiar strength—the petrous bones and the basilar portions of the occipital—seem, on the contrary, to be the very seats of election for fractures of the base.

For convenience of comparison, I have arranged the drawings in classes according to the nature and direction of the violence which produced them. Wherever there seemed to be doubt as to these points I have indicated this fact by a query mark (?). The direction of the violence is indicated, wherever this could be done, by an arrow pointing to the point of impact.¹

CLASS A¹. *Fractures caused by blows on the frontal region.* Of this class I have only two cases. One caused by a kick from a horse above the right eyebrow, causing a direct fracture here, and an indirect meridional and oblique fracture of the parietal bone of the same side. The other case presents a fracture caused by a blow

¹ The plates published at the end of this paper have been prepared from those presented to the College, so that a single diagram may exhibit a number of fractures caused by the same sort of force.

with the handle of a pitchfork, high up on the frontal region. The fracture is in the base, is meridional, and passes from the right orbital plate through the sphenoid bone and the basilar process of the occipital, leaping across the foramen magnum, from the back edge of which start two converging fissures which meet in the cerebellar fossa on the left side, and end above the groove for the lateral sinus.

CLASS A². *Fractures caused by falls upon the frontal region.* Of these I have thirteen cases. Twelve present meridional fissures; five of them being directly longitudinal, three of these passing directly through the whole basi-sphenoid bone. Seven are oblique: two of them bifurcated, and one passing through the whole basi-sphenoid bone; one passes from the point of impact to the lower part of the ridge for the straight sinus, after having passed across the middle of the petrous bone and encircled the foramen magnum. One shows a ring fracture, in addition to a meridional fracture from the frontal bone to the junction of the petrous with the basi-sphenoid. One is directly opposite to the point struck, is extensive and bifurcated.

CLASS B¹. *Fractures caused by blows on the occipital region.* Of these I have only two cases. One was caused by a spent ball striking the occiput to the left of the middle line, and shows an independent meridional fracture passing alongside of the internal ridge to near the foramen magnum, then crossing the petrous bone, dividing it transversely to its principal axis, and ending in the foramen spinosum. The other case is a specimen from one of Perrin's experiments, in which the skull was thrown on a stone pavement covered with a layer of India-rubber. There is a separation of the coronal suture, and a prolongation of this as a bifurcated fissure in the right squamous bone. This specimen shows a division at right angles to the meridian, which may be due to an unusually weak union in the coronal suture, or to some peculiarity of the experiment. I have included this specimen among my drawings, because it is diametrically opposed to the bursting theory. But I think an experiment which involves throwing a skull detached from the body, cannot be considered very reliable in comparison with those in which the skull is fixed.

CLASS B². *Fractures caused by falls, striking upon the occipital region.* Of these I have twenty-one cases. All show meridional fractures. Two of these pass directly through the crest for the lodgement of the straight sinus to the foramen magnum. One passes to the foramen magnum near this crest. Two pass through the whole of one side of the occipital bone, and one splits off a piece of the parietal, and separates the lambdoid suture in part. One divides the frontal bone into halves. Six pass round the foramen magnum on one side, three dividing the petrous bone longitudinally and one transversely. One shows a longitudinal fracture passing across the foramen magnum and dividing the basi-sphenoid bone, as well as a partial ring-fracture. In two the fissure passes meridionally round the side of the head. One shows an independent fissure on each side, in the parietal bones.

CLASS B³. *Fractures due to blows on both the forehead and occiput.* One such case I have found recorded by Herpin, in which there was a succession of bumps on each of these parts. The resulting fracture is a long fissure, passing longitudinally from the internal occipital protuberance to the foramen cæcum, passing round the foramen magnum, very close to it, and dividing the whole of the basi-sphenoid: a beautiful meridional fissure.

CLASS C¹. *Fractures caused by compression in a longitudinal direction: accidental.* Hewett records two cases of this sort. In the first, a man fell on the back of his head, and a piece of timber fell on his forehead. The fissure is independent, and partly meridional. It divides longitudinally the middle of the horizontal plate of the ethmoid bone and the middle of the body of the sphenoid bone, passing then to the right through the greater wing of this bone, and bifurcating before passing in two fissures upon the squamous plate of the temporal bone. In the second, the history is far from clear, but it seems that the fracture was caused by the compression of a cartwheel passing across the forehead. The fracture is meridional and exactly like several in the next class.

CLASS C². *Fractures caused by compression in a longitudinal direction: experimental.* Of these I have nine cases. Six show meridional fissures. One divides the skull from front to back over the vault. Three divide the skull to an equal extent through the

base, passing round the foramen magnum. In two there are two independent fissures. In one of these cases one of the two fissures is not meridional. Three of the cases show complicated fissures which may be due more to crushing than to bursting.

CLASS D¹. *Fractures from blows on the parietal region.* Of these I have only four cases. All show meridional fissures. Three pass straight down to the apex of the petrous bone, and one passes also up to the vertex.

CLASS D². *Fractures caused by falls, striking on the parietal region.* Of these I have fifteen cases, in all of which I think the fractures may be considered meridional. Four pass along the horizontal equator of the skull. Seven are transverse, three crossing the base from side to side, two going half way across, one involving only the ends of the petrous bone, and one passing across the vault at the back part of the parietal bones, and then passing forward to the base. Four are diagonal, two of them passing across the sella turcica.

CLASS E¹. *Fractures caused by compression in a transverse direction: accidental.* Of these I have five cases. In all, the fractures are transverse and meridional. Two pass across the basisphenoid bone and upward on both squamous bones. In one both parietal bones are split independently, the fissures passing down through the petrous bone. In one the coronal suture was separated, and a piece broken out of each parietal, beside an independent fracture of the occipital and petrous bones at the base on one side.

CLASS E². *Fractures caused by compression in a transverse direction: experimental.* Of these I have five cases. In all, the fissures are transverse and meridional. In four the basi-sphenoid is divided transversely, and in three the fissure involves also the temporal bones. In one case the coronal suture is disarticulated.

CLASS F. *Fractures caused by falls, striking on the temporo-frontal region.* Of these I have only two cases. In one the fracture is meridional; in the other it is equatorial, and seems to illustrate the shoving of the posterior half of the skull over the anterior half by the impact of the spinal column on the base in an oblique direction.

CLASS G. *Fractures caused by compression in a diagonal direction: experimental.* Of these I have five cases. In four the fissures are meridional, two being quite complicated. In one case there is a separation of the posterior inferior angle of the parietal bone, and the dorsum of the sella turcica is broken off.

CLASS II¹. *Fractures caused by blows on the vertex: accidental.* Of these I have six cases. In all, the fractures are meridional; in five they are transverse and in one longitudinal.

CLASS II². *Fractures caused by blows on the vertex: experimental.* Of these I have three cases. All of them show beautiful meridional fissures, one transverse and two longitudinal, one of the latter dividing the skull completely into halves.

CLASS II³. *Fractures caused by falls upon the vertex: accidental.* Of these I have seventeen cases. In all, the fissures are meridional and can, I think, be attributed to a burst. In one the front half of the skull is divided longitudinally, and in one the posterior half is similarly divided. In one the fissure divides the skull into halves longitudinally; in two it divides it into halves transversely. In one the basilar artery was found caught in a transverse fissure of the basilar process of the occipital bone.

CLASS J¹. *Fractures caused by falls upon the condyles (transmitted from feet): accidental.* Of these I have only three cases. In two both posterior clinoid processes were broken off—which can be attributed to the lengthening of the antero-posterior diameter of the skull—and there was a transverse fracture of the apex of the petrous bone. In the third case there is only a longitudinal fissure of the horizontal plate of the ethmoid bone on one side.

CLASS J². *Fractures caused by blows on the condyles: experimental.* Of these I have four cases. In all of them the dorsum of the sella turcica has been torn off by the elongation of the antero-posterior diameter of the skull. In two cases this is the only fracture. In one case the whole base is also divided transversely, the fissure passing across the basilar process of the occipital bone. In one case there are also three independent fissures, all transverse.

CONCLUSION.

The analysis of these 119 cases shows that 111 present fissures which correspond to what might be expected from an application of the principles of the "bursting theory," and only 8 seem to contradict it. This result, which has surprised me by its apparent completeness, seems to establish this theory by the best test which we can apply to it, so that it appears to rest upon a very firm tripod of reasoning, experiment, and clinical observation.

I trust it will not be supposed that, in making so much of the bursting theory in this paper, I have overlooked the fact that there are fractures which cannot be accounted for by it. There are some fractures in which the force applied is so great, and acts in such a manner, that the skull is crushed so as to hide any evidence of the play of its elastic properties, the fracture being of a comminuted sort; and there are others in which, as I have noted in passing, one segment of the skull seems to be shoved over the other by forces of pressure and counter-pressure which require some study before their mode of operation can be understood. In this connection it is of importance to learn in any case the position which the skull has held in relation to the spinal column, or to any body capable of exerting counter-pressure. No less is it important not to overlook the counter-pressure which is caused by the simple *vis inertiae* of the skull, and its contents.

But it would be impossible to speak of all the influences which may modify the strict application of any one theory in regard to fractures of the skull. I have laid before you all the evidence which I now can in re-

gard to this matter; and I must close with the expression of my own conviction that the supreme law governing the production of indirect fractures, is that which depends upon the fact that the skull is practically a hollow elastic case, approximately oval in shape, and which may be briefly formulated as follows: When a sufficient force is applied to any curvilinear part of the skull, if this part do not give way immediately, the axis of the skull lying in the same line as that of the applied force is shortened; all the axes lying in planes at right angles to this line are correspondingly lengthened, with a proportional lengthening of their circumferences, and separation of their meridians; so that the direct depressing force is converted into an indirect disruptive force acting at right angles to the direction of the former. The effect is to produce a fissure, or fissures, which will have a general meridional direction.

The application of this law is subject to certain modifications due to the anatomical and architectonic peculiarities of the skull, its coverings and contents, and to certain exceptions due to the amount and velocity of the force applied as well as to the coming into play of peculiar counter-forces.

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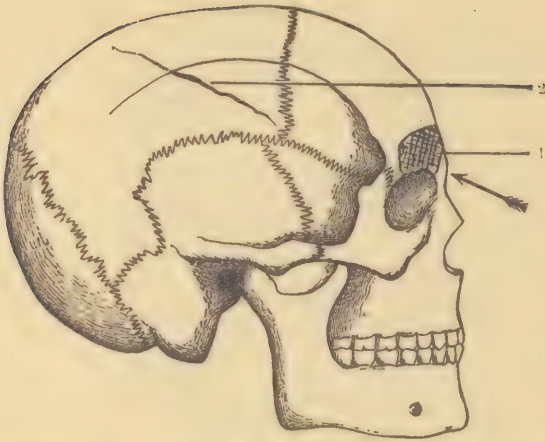
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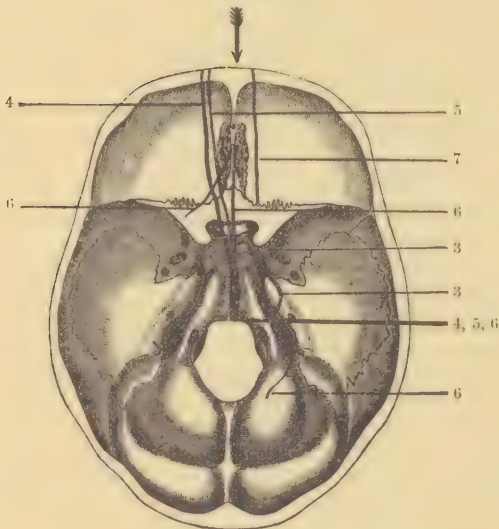
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PLATE I.



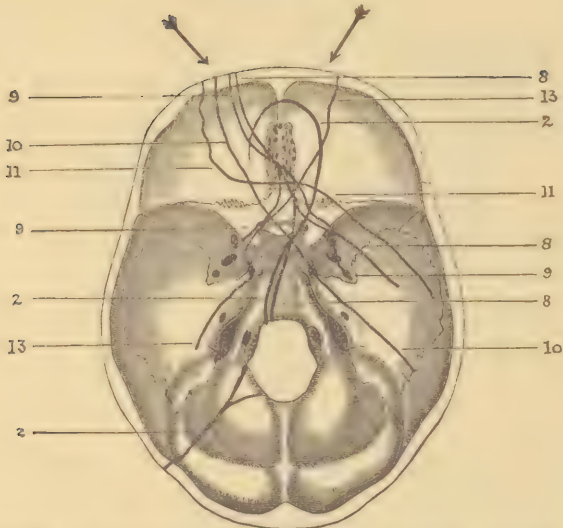
Independent, meridional fissure caused by kick by a horse;
skull broken in above orbit.

PLATE II.



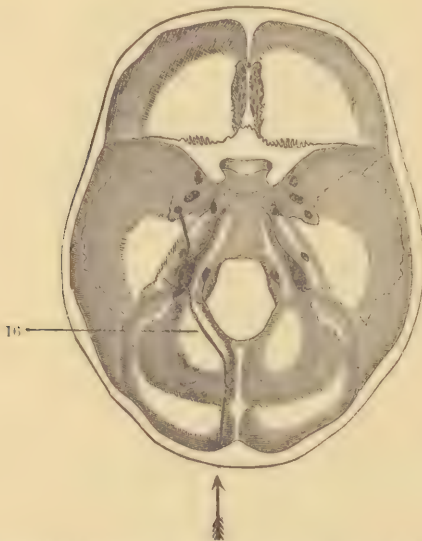
Fissures caused by force applied to forehead ; by falls.

PLATE III.



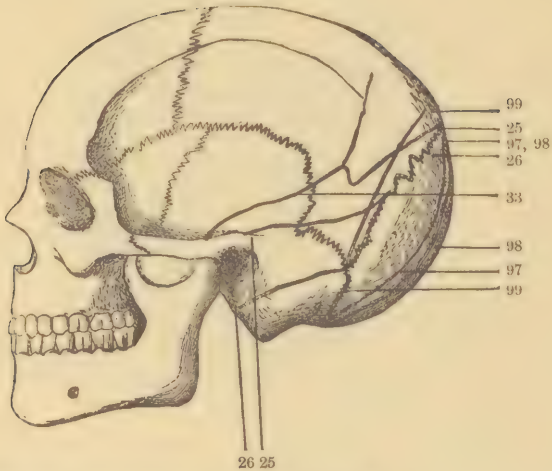
Fissures caused by force applied to forehead in an oblique direction ; by falls.
No. 11 continued up over frontal bone to beyond coronal suture on left side.

PLATE IV.



Fissure caused by force applied to occiput ; blow by a spent ball.

PLATE V.

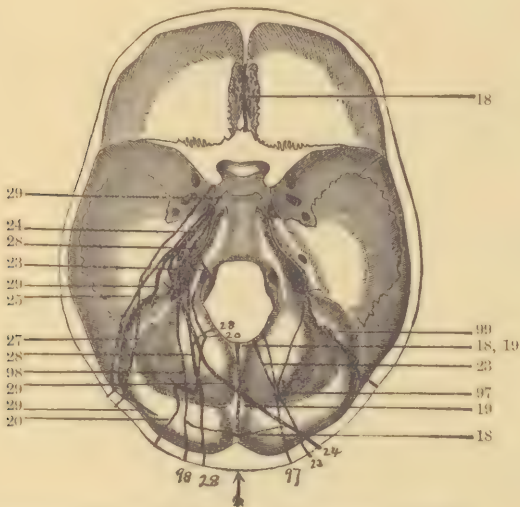


Fissures caused by force applied to occiput; by falls.

No. 25 continued to apex of petrous bone, through anterior inclined plane.

Nos. 33, 97, and 99, were on right side of skull. (See also Plate VI.)

PLATE VI.



Fissures caused by force applied to the occiput; by falls.

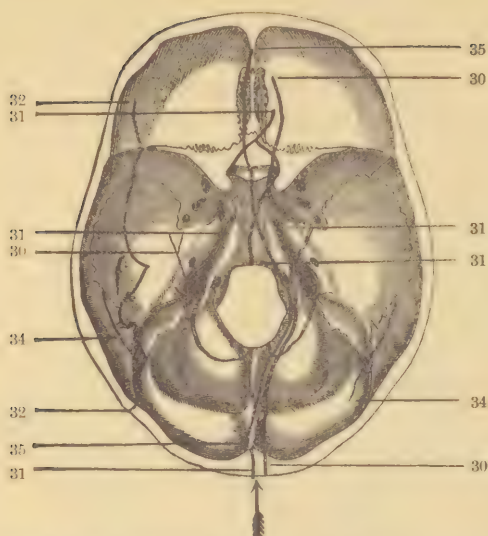
No. 97 passed up on right to lambdoidal suture.

No. 98 passed up on left to lambdoidal suture.

No. 99 passed up in front of lambdoidal to near sagittal suture.

No. 25 passed round left side to root of zygoma. (See also Plate V.)

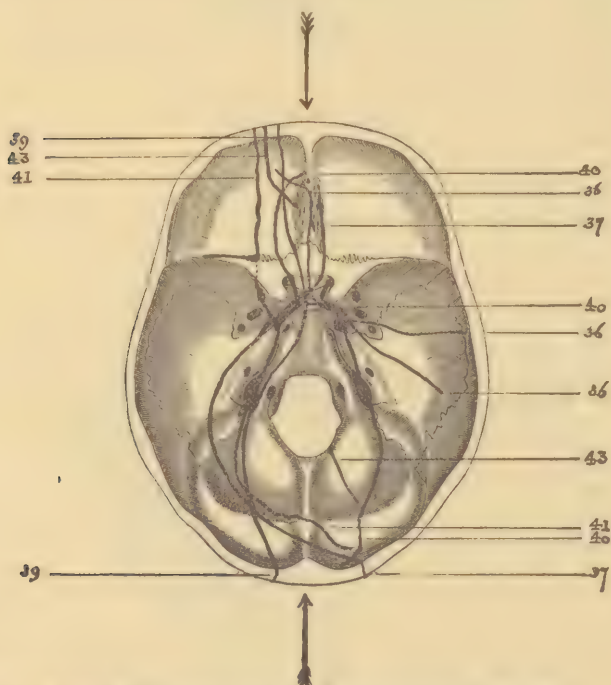
PLATE VII.



Fissures caused by force applied to occiput; by falls.

One fissure (No. 35) caused by force applied to occiput and forehead alternately.

PLATE VIII.



Fissures caused by compression in fronto-occipital diameter.

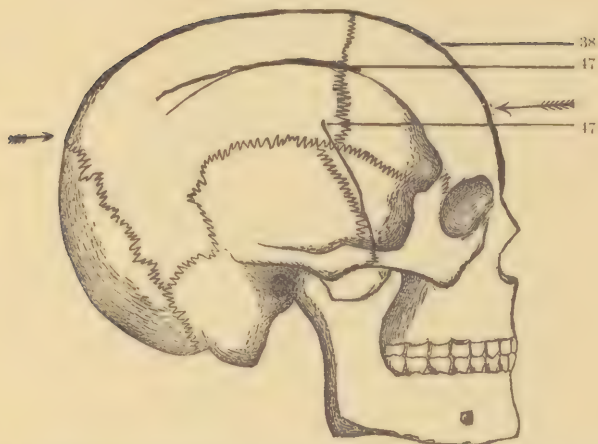
Nos. 36 and 37, accidental.

Nos. 39, 40, 41, and 43, experimental.

No. 37 passed up and forward on right parietal bone to near its middle.

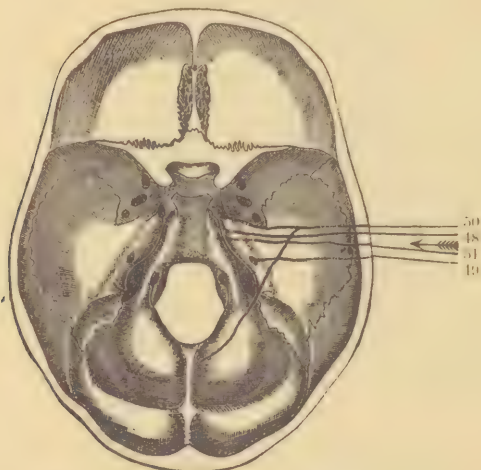
No. 43, fissure in cerebellar fossa involved vitreous table alone.

PLATE IX.



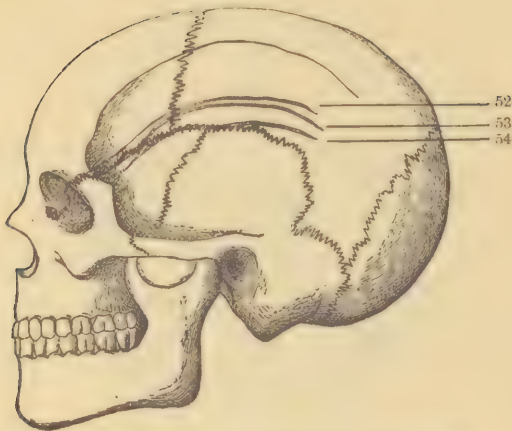
Fissures caused by compression in occipito-frontal diameter ; experimental.
No. 47 was on left side of skull.

PLATE X.



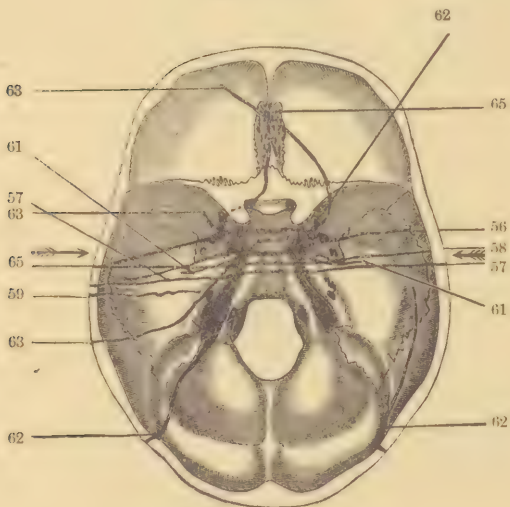
Fissures caused by blows on side of head.
No. 51 passed up to sagittal suture.

PLATE XI.



Fissures caused by falls, striking on parietal boss.

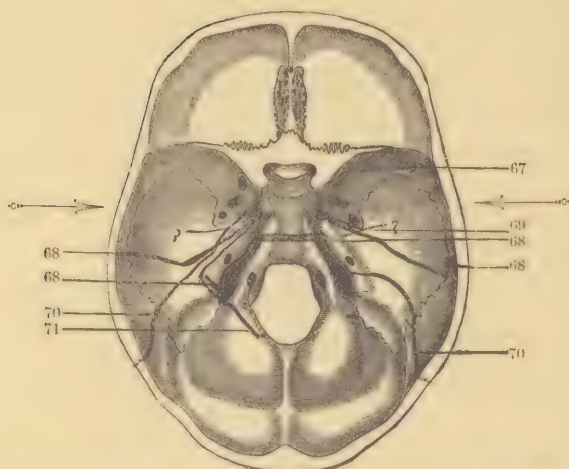
PLATE XII.



Fissures caused by falls, striking on side of head.

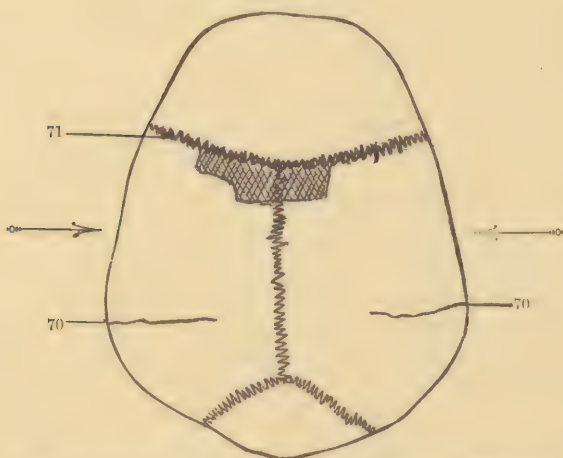
No. 62, fracture at back of skull passed over vault through both parietal bones, caused by fall on left parietal boss.

PLATE XIII.



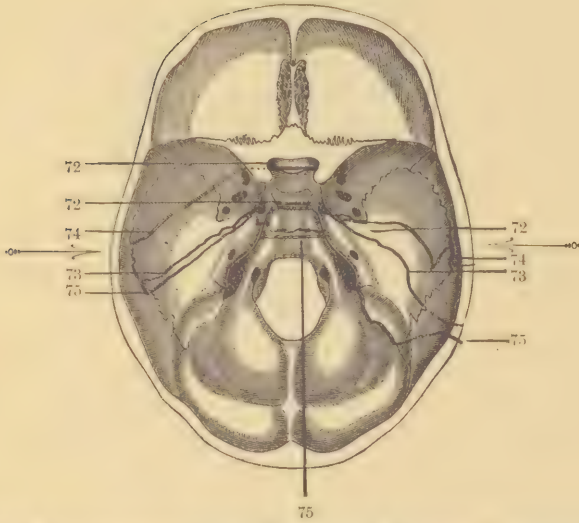
Fissures caused by compression in transverse diameter; accidental.
 No. 69, extension of fissure into side of base imperfectly described.
 No. 70, fissure on each side continued upward in coronal direction half way to sagittal suture. (See also Plate XIV.)
 No. 71, principal fissure was in coronal suture; the fracture at base hard to distinguish, as patient survived forty years. (See also Plate XIV.)

PLATE XIV.



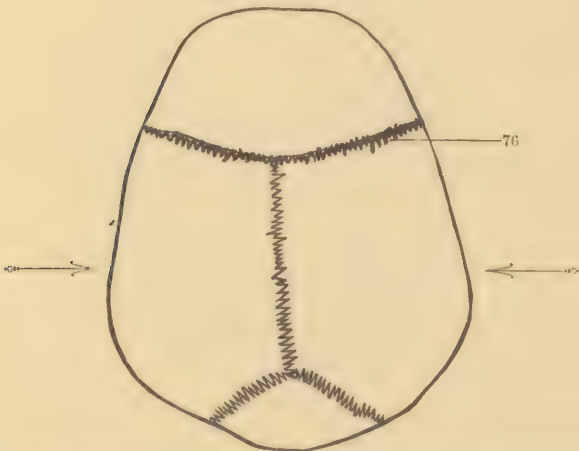
Fissures caused by compression in transverse diameter.
 (See also Plate XIII.)

PLATE XV.



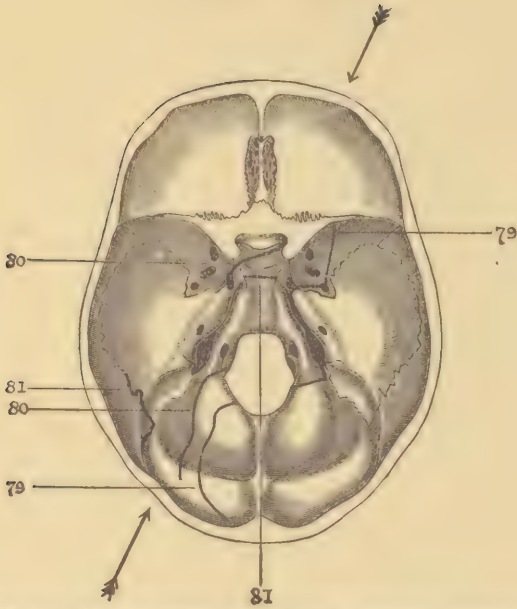
Fissures caused by compression in transverse diameter ; experimental.

PLATE XVI.



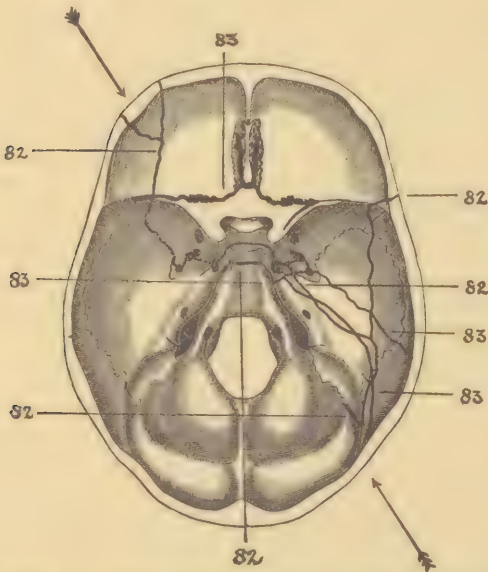
Fissure caused by compression in transverse diameter ; experimental.
No. 76, separation of coronal suture.

PLATE XVII.



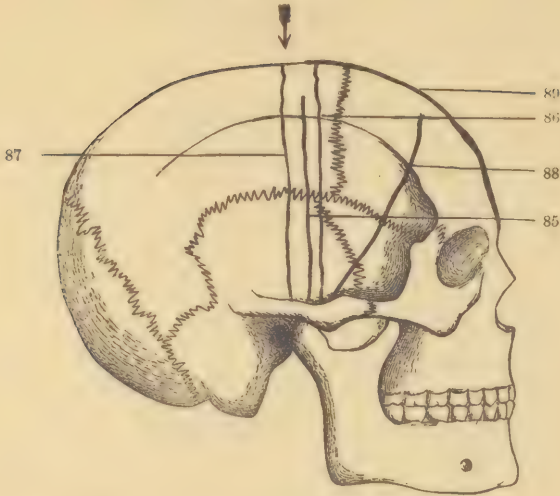
Fissures caused by compression in diagonal direction ; experimental.

PLATE XVIII.



Fissures caused by compression in diagonal diameter ; experimental.

PLATE XIX.



Fissure caused by blows on top of head ; accidental.

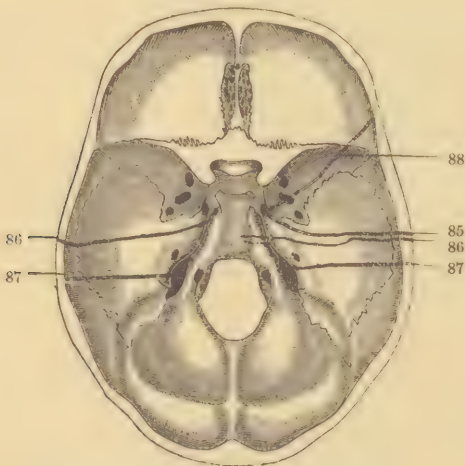
No. 85. See also Plate XX.

Nos. 86 and 87 passed across whole of vault and into base on both sides. (See also Plate XX.)

No. 88, fissure passed to carotid canal ; end of petrous bone also broken off. Child, four years old. Billet of wood fell considerable distance, struck on forehead. (See also Plate XX.)

No. 89, man struck on "crown of head" by a piece of iron falling a considerable distance.

PLATE XX.



Fissures caused by blows on top of head ; accidental.

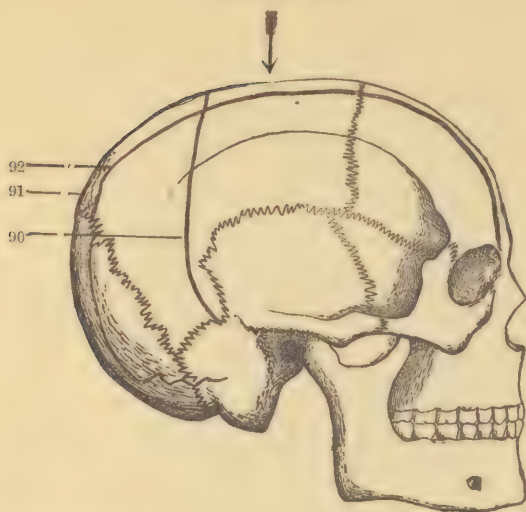
No. 85, fissure passed up to near sagittal suture. (See Plate XIX.)

No. 86, fissure completely bisected vault. (See Plate XIX.)

No. 87, vault crushed in and fissure connected with those in base. (See Plate XIX.)

No. 88, fissure extended up to centre of left frontal bone. (See Plate XIX.)

PLATE XXI.

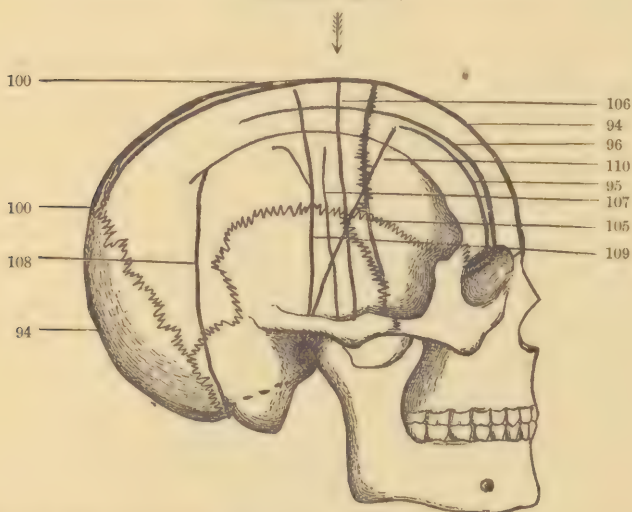


Fissures caused by blows on top of head ; experimental.

No. 91 passed to foramen magnum to left of median line. Placed on right side here for convenience.

No. 92 divided base from front to back, splitting basi-sphenoid.

PLATE XXII.



Fissures caused by falls on top of head ; accidental.

No. 94 divided skull into halves longitudinally. (See Plate XXIII.)

No. 95 passed to sella turcica. (See Plate XXIII.)

No. 96 passed to foramen magnum. (See Plate XXIII.)

No. 100 passed to foramen magnum. (See also Plate XXIII.)

No. 106 divided skull into halves. (See Plate XXIV.)

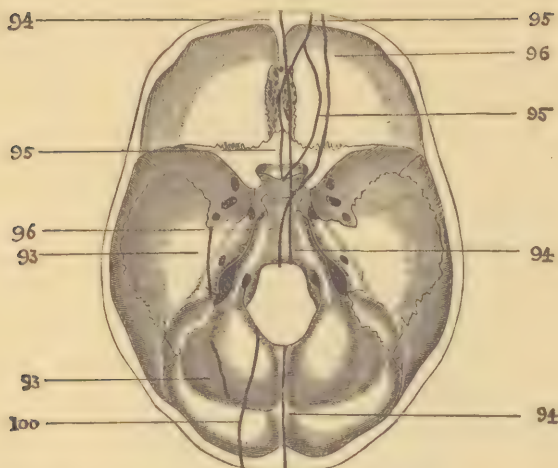
Nos. 107 and 108 were on *left* side. (See Plate XXIV.)

No. 109, fissure passed to foramen magnum. (See Plate XXIV.)

No. 110 fissure passed to jugular foramen. (See Plate XXIV.)



PLATE XXIII.



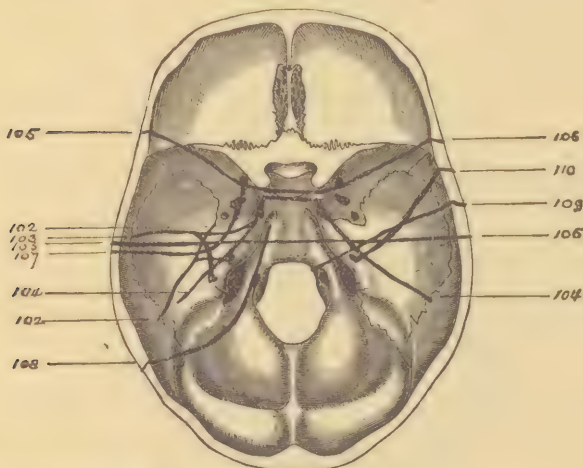
Fissures caused by falls on top of head ; accidental.

No. 94, fissure divided skull into halves longitudinally. (See Plate XXII.)

Nos. 95, 96. See also Plate XXII.

No. 100 passed up to apex of lambdoidal suture and through sagittal to frontal bone. (See also Plate XXII.)

PLATE XXIV.



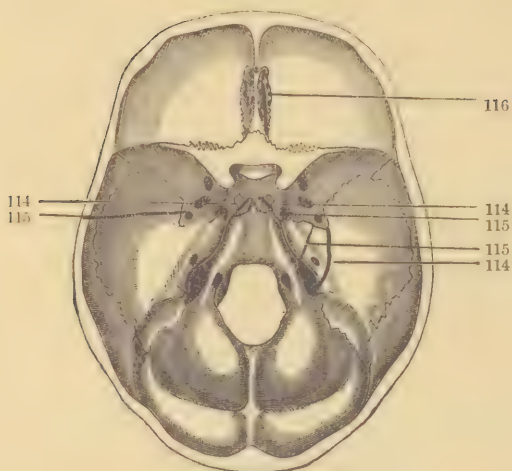
Fissures caused by falls on top of head ; accidental.

Nos. 105 and 106 divided skull into halves. (See Plate XXII.)

No. 107 passed up on left side to middle of parietal bone. (See Plate XXII.)

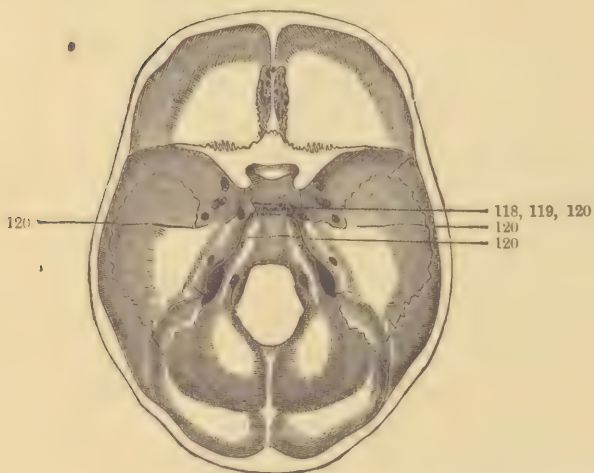
Nos. 108, 109, 110 passed up to near vertex. (See Plate XXII.)

PLATE XXV.



Fissures caused by falls on feet; accidental.

PLATE XXVI.



Fissures caused by blows on condyles; direct or transmitted; experimental.

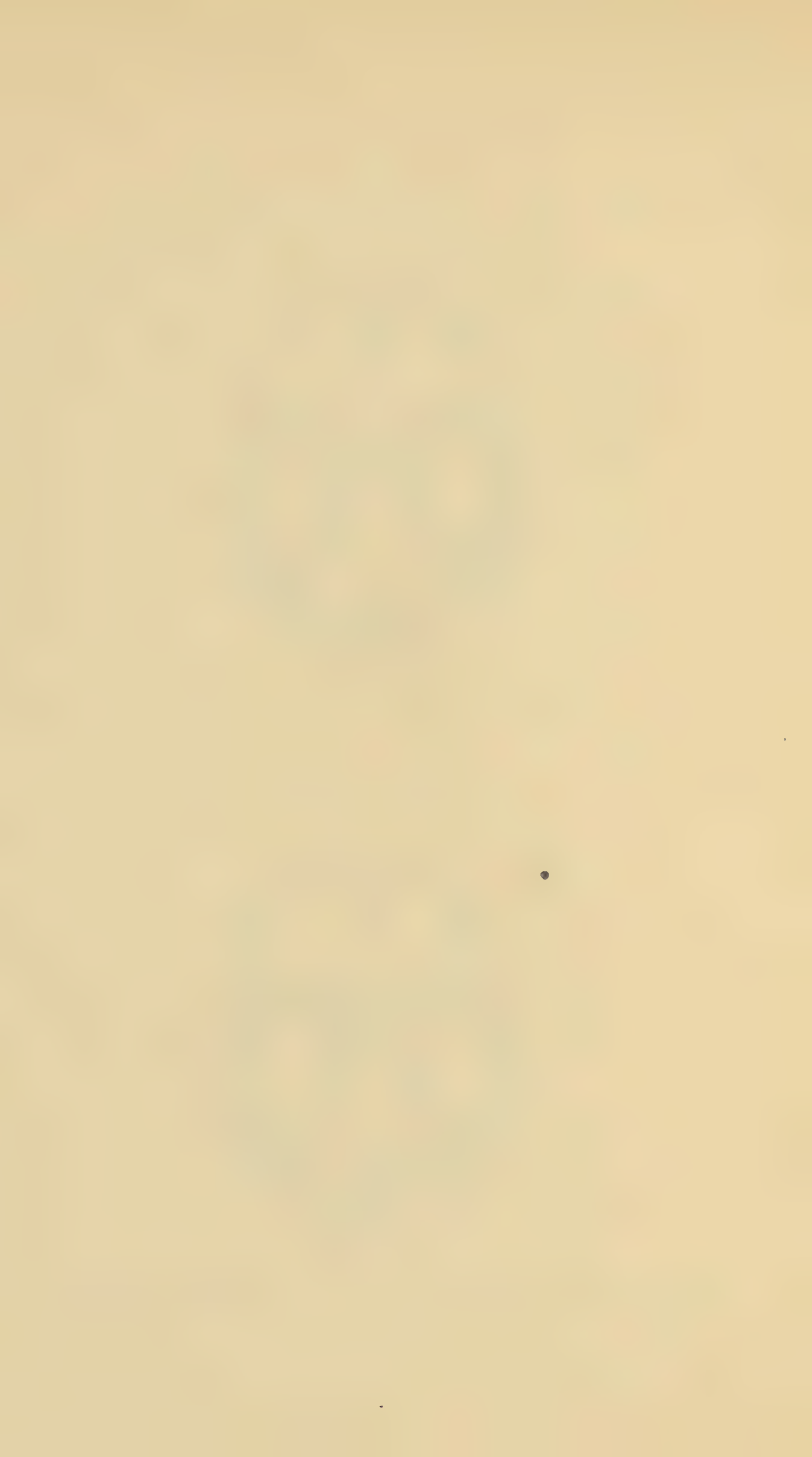
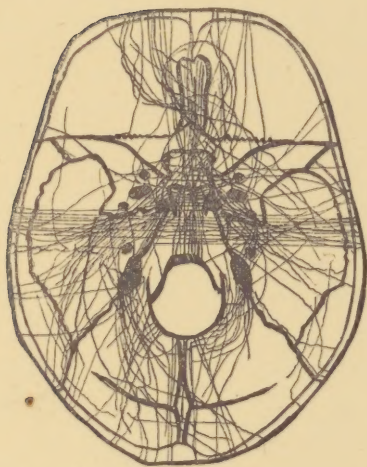


PLATE XXVII.



Lines of fissures in 100 cases. It has been impossible to represent all that passed through the basi-sphenoid, either longitudinally or transversely, or those which passed along the anterior inclined plane of the petrous bone.

